

# MANNED - UNMANNED VEHICLES CONVOY

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## ABSTRACT

This paper describes the project undertaken by DSO National Laboratories to demonstrate convoy movement involving a manned vehicle and two Unmanned Ground Vehicles (UGVs) along roads and dirt tracks at speeds up to 35 km/h and 20 km/h respectively.

The project work included development of UGV hardware, vehicle controller, sensor suite comprising of short and long range sensors, and high speed navigation algorithms. The long-range sensors allow the UGV to plan a coarse path early, leaving the local terrain navigation to be done instantaneously with higher resolution sensing from the short-range sensors. Navigation behaviors such as front vehicle following, way-point following, road following and obstacle avoidance were developed and tested to enable the UGV to maneuver robustly under varying environments and scenarios.

The project also explored the concept of Manned-Unmanned vehicles team. Some basic tactical behaviors such as Line Up, Convoy Movement, Admin Halt and Tactical Halt were developed and demonstrated on the UGVs. It was confirmed that by equipping the UGVs with these behaviors, the warfighter was able to operate the UGVs easier via the Operator Control Unit (OCU).

Throughout the project, a series of data collection and testing for the individual modules were conducted to understand the optimal system configuration that can best meet the performance specifications. A final demonstration in our local terrain was conducted to validate the performance of the UGV

embarked on a project in mid 2006 to explore the performance of various sensors and algorithms in our local terrain and climate. Another objective is to explore the use of Manned-Unmanned teaming concept to enhance the operational effectiveness of the warfighter. In late 2007, some basic tactical behaviors were demonstrated on the UGVs. This led to further development effort to enhance the mobility for a single UGV over difficult terrain. A final UGV demonstration was conducted successfully in early 2008.

This paper is organized as follows: Section 2 describes the system design of the UGV and the manned vehicle. Section 3 elaborates on the autonomy of the UGV to handle high level commands from the warfighter. Section 4 concludes with the achievements and provides recommendations for future work.

## 2 SYSTEM DESIGN

This section gives an overview of the system design from the hardware and software perspectives.

### 2.1 System Overview

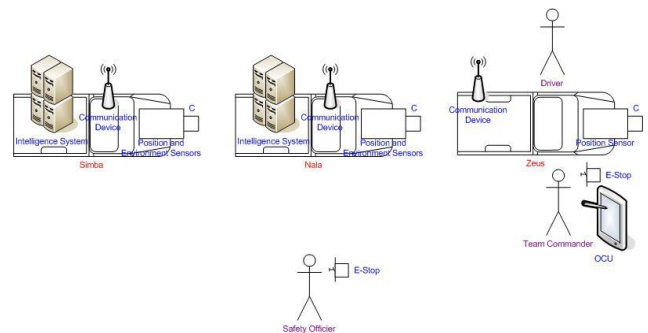


Figure 1 System overview

## 1 INTRODUCTION

The DARPA Grand and Urban Challenges have fueled advancement in UGV technologies for off-road navigation and in urban environment. DSO had

Figure 1 illustrates the system overview. The team comprises of a manned vehicle and two UGVs. The three

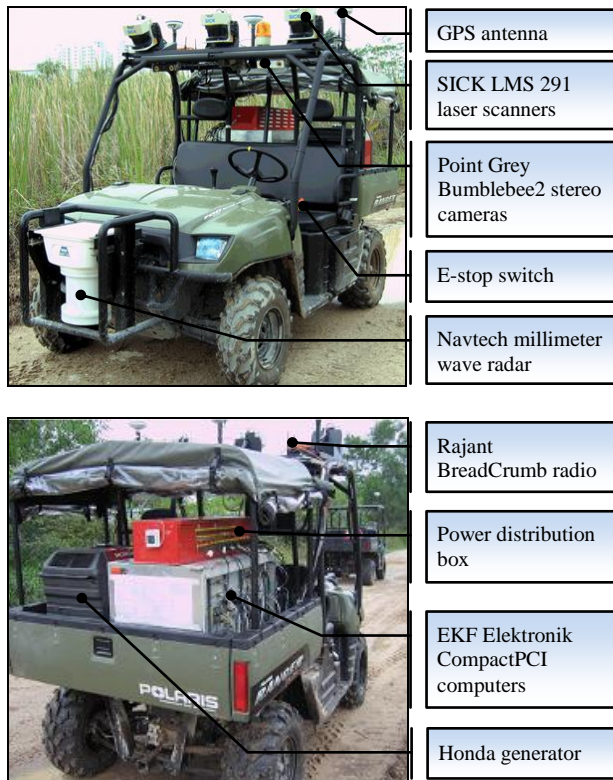
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vehicles are linked via the communication devices. The manned vehicle has an OCU for the warfighter to control and monitor the UGVs. In addition, it has the localization subsystem to provide its position and velocity information. The UGVs were equipped with the necessary sensors and computing resource. Two Emergency-Stop (E-Stop) mechanisms, one on the UGV and the other with Safety Officer, will provide the secondary means to stop the UGV safely.

## 2.2 Hardware Design

### 2.2.1 UGV Platform

Figure 2 below shows the configuration of the electronic equipment onboard the UGV.



**Figure 2 UGV hardware configuration**

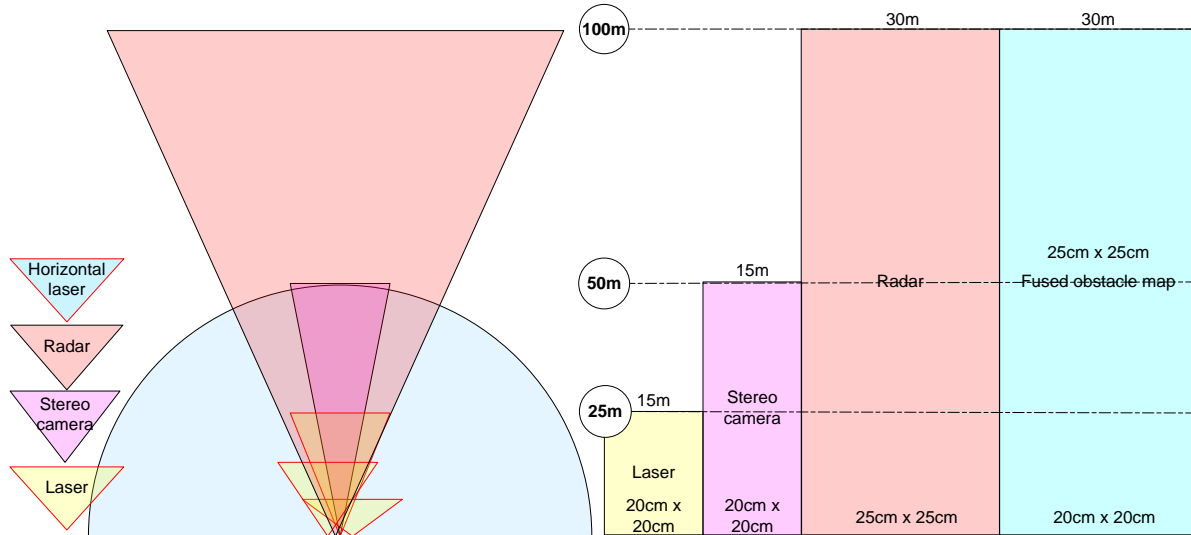
The platform for the UGV is a Polaris Ranger XP, retrofitted by Singapore Technologies Kinetics (STK) for Drive-By-Wire (DBW) operation. Servomotors and encoders had been installed without comprising the safety of the platform. The vehicle can still be driven manually as and when required.

Each UGV is equipped with a sensor suite comprising of short and long range sensors. The objective of the suite is to sense the region in front of the UGV for autonomous navigation along roads and dirt tracks at speeds up to 35 km/h and 20 km/h respectively. The following lists the sensors and their purpose:

- SICK LMS 291 laser scanner for obstacle detection and terrain mapping. Three scanners are mounted on the roof of the UGV and tilted downwards to scan the ground approximately at 5m, 15m and 25m in front of the UGV.
- NavTech 77GHz millimeter wave radar for long range obstacle detection. It is mounted on the front bumper to scan 100m forward.
- Point Grey Bumblebee 2 stereo camera for obstacle detection, front vehicle detection, and road and lane detection. Two cameras are mounted just below the roof, tilted down to detect obstacles up to 20m in front of UGV and detect road and lanes up to 50m ahead.

Figure 3 illustrates the area of coverage for each sensor. Other electronic equipment onboard the UGV include the following:

- EKF Elektronik CompactPCI computer for processing the sensors' data and autonomous navigation. Up to five computers are used and they are housed inside an enclosed chassis on the rear of the UGV. Suitable shock isolation and thermal cooling solution are used.
- Integrated Navigation System comprising of DGPS/IMU/wheel encoders to provide pose and speed information to the system.
- Rajant BreadCrumb ME for wireless data communication between vehicles and video streaming for tele-operation. It is mounted below the roof.
- D-Link DCS-6620 Pan/Tilt/Zoom internet camera to provide video for tele-operation. It is mounted below the roof near the driver seat.
- Safety subsystem provided by STK. It consists of an E-stop switch mounted on the UGV and a remote E-stop radio carried by the Safety officer.
- Power distribution box provided by STK. It is mounted on the rear computer chassis.
- 3 kW Honda generator for supplying power to all onboard electronic equipment. It is mounted on the rear of the UGV next to the computer chassis.



**Figure 3 Sensor coverage**

### 2.2.2 Manned Vehicle Platform



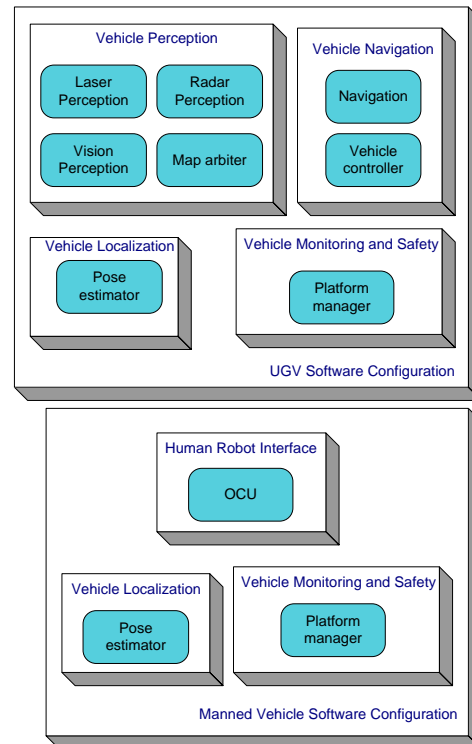
**Figure 4 Manned vehicle**

The platform for the manned vehicle is a Polar Ranger 4x4. It is simpler compared to the UGV and consists of the following equipment:

- Panasonic Toughbook used as an OCU for control and monitor of the UGVs. It is mounted on the dashboard at the passenger side.
- Integrated Navigation System comprising of DGPS/IMU/wheel encoders to provide pose and speed information to the UGVs for convoy movement.
- Rajant BreadCrumb ME for wireless data communication between vehicles and video streaming for tele-operation. It is mounted below the roof.

### 2.3 Software Design

Figure 5 shows the overall software configuration for the manned vehicle and the UGV. There are a total of five different subsystems, each handling the capabilities required of the system. Each subsystem consists of module(s) to address a specific function. New modules could be added to enhance the autonomy of the UGV.



**Figure 5 Software configuration**

The Vehicle Perception subsystem comprises of active and passive sensors and a map arbiter. The map arbiter is designed to receive environment information (in the form of occupancy/confidence maps) from the laser, radar and vision perception modules and provide fused terrain/environmental information for the Vehicle Navigation subsystem.

The Vehicle Navigation subsystem is the “brain” for the UGV. It controls the behavior of the UGV through the following:

- Change the behavior configuration according to the selected operation mode.
- Follow the path taken by the front vehicle.
- Maintain vehicle separation and ordering.
- Follow the road (and lane) or track.
- Seek to reach next waypoint while avoiding obstacle.
- Adjust speed based on long range sensing.
- Ensure vehicle do no tip/roll over.
- Discourage steering oscillation.
- Adjust speed for vehicle base on terrain roughness.
- Plan a path to the next waypoint in pre-planned route.
- Plan a path to the ‘waypoint’ provided by front vehicle.
- Track the path.

The Vehicle Localization subsystem interfaces to the integrated DGPS/IMU/wheel encoders to provide the real-time position, orientation, and velocity for Vehicle Perception and Vehicle Navigation subsystems.

The Vehicle Monitoring and Safety subsystem primary purpose is to ensure that all the software modules on the UGV are running and the UGV is in the correct mode. It does not have any intelligence. It serves as the interface between the OCU and the software modules on the platform.

The Human Robot Interface (HRI) provides facilities to give the warfighter command & control and monitoring capabilities. The requirements for the HRI are as follows:

- To monitor the status of all platforms and their modules easily; detect any loss of communications or module failure.
- To send Mode change commands to each UGV.
- To set separation distance for convoy movement for each UGV.

- To provide tele-operation support for each UGV by means of joystick control.
- To provide means for an independent video source control via an IP Camera mounted on the UGV.

The middleware that binds these subsystems is based on JAUS version 3.2, implemented by DSO. Connectionless UDP protocol is used for message passing.

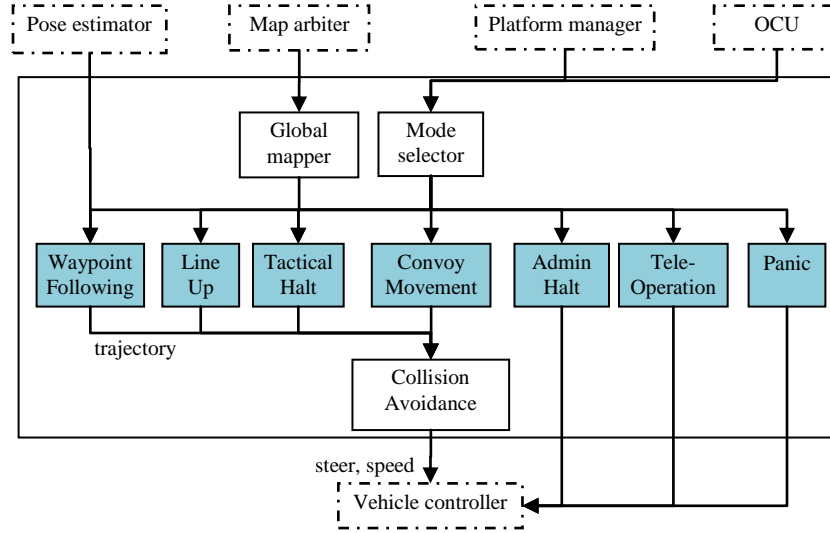
### 3 NAVIGATION

The navigation module is the brain of the UGV, allowing it to navigate autonomously based on commands such as operation mode or target waypoints. The module receives inputs from the Vehicle Localization subsystem and the Vehicle Perception subsystem and the commands from the OCU. The outputs are speed and steer commands to the vehicle controller module.

Figure 6 gives an overview of the navigation module. The colored boxes correspond to the seven operation modes that the warfighter can select and the dotted boxes are the external modules that send/receive information to/from the navigation module.

The following lists the functionality of each block:

- Global mapper – to join all local obstacle maps from map arbiter module.
- Mode selector – to select the possible mode based on the OCU selection and existing input.
- Admin Halt – stop the vehicle.
- Panic – stop the vehicle immediately.
- Tele-operation – to allow the user to control the vehicle directly.
- Line-Up – take up position behind the manned vehicle prior to convoy movement.
- Tactical Halt – stop the vehicle along the side of the road.
- Waypoint following – follow the preplanned waypoints.
- Convoy Movement – follow behind the front vehicle maintaining desired separation distance. When the manned vehicle stops, the UGV will stop.
- Obstacle avoidance – reactive planner that avoid obstacles guided by the planned trajectory.



**Figure 6 Navigation module architecture**

Five behaviors are designed to achieve the above seven operation modes. Table 1 summarizes the algorithm for each behavior.

Behavior	Algorithm
Road Follower	Rule-based
Front Vehicle Path Tracker	Rule-based and Adaptive Pure pursuit
Collision Avoidance	Trajectory Evaluation
Path Planner and Tracker	Adaptive Pure pursuit
Vehicle Stability Controller	Rule-based

**Table 1 Algorithm for each behavior**

Road Follower behavior – to keep the UGV moving along the road/track. This is achieved by evaluating all possible trajectories on the road and assigning cost values to the trajectories based on the mode selected by the user, the road map from the Vehicle Perception subsystem and the rules of driving (e.g. keeping left for oncoming vehicles). The trajectories generated are guided by either the manned vehicle's path or the predetermined road network.

Front Vehicle Path Tracker behavior – ensures that the UGV follow the manned vehicle in a specified order/rules (via the OCU) during the Convoy Movement mode. The output of this behavior is a path travelled by the manned vehicle guiding the road follower.

Collision Avoidance behavior – to avoid all obstacles. This is achieved by giving cost values to the trajectories based on the trajectory distance to obstacles and distance from guiding path. The trajectory cost value is combined with the Road Follower's trajectories cost value to determine the local optimal that is close to global optimal trajectory. This trajectory is further tracked by using the

adaptive pure pursuit algorithm to output steer and speed commands.

Path Planner and Tracker behavior – to allow the user to predetermine a path and command the UGV to follow the planned path in the event that it loses communication link with the manned vehicle. It is achieved by passing this planned path to the road follower and the Collision Avoidance behavior to determine the current trajectory. This behavior is not activated in normal situations when the manned vehicle is available.

The selected trajectory is then further analyzed with a dynamic constrained velocity algorithm in the Vehicle Stability Controller behavior. This will enable the UGV to follow the desired path safely, preventing side-slip and roll-over which is common in rough terrain. This behavior takes in the INS measurements and determines the constraints of command space (steer and speed) of the UGV.

The UGV was successfully tested in a military training area. The entire route distance is 8 km. The identified algorithms (adaptive pure pursuit, trajectories evaluation and dynamic constraints) had displayed their functionality during the trials and demonstrations. The maximum speed reached was 25 km/h.

The project had also tested simple tactical behaviors such as Convoy Movement, Line up and Tactical Halt during the development and system trials on STK test track.

In order to make the UGV more robust in mission execution, there is a need to enhance awareness on the terrain. The road and obstacle maps are insufficient to

allow the UGV to achieve some tactical behaviors robustly. For example, in the Tactical Halt mode, the UGV needs to identify a good concealment cover.

#### 4 CONCLUSION AND FUTURE WORKS

The project had been a rewarding experience. Demonstrations of convoy movement involving a manned vehicle and two UGVs were conducted. The performance of a single UGV was also demonstrated by operating it autonomously over difficult terrain.

It was confirmed that by equipping the UGVs with these behaviors, the warfighter was able to operate the UGVs easier via the Operator Control Unit (OCU). Going forward, it would be worthwhile to explore the use of HRI technologies to enhance the Manned-Unmanned teaming concept. The warfighter could be involved to guide the UGV in handling the more complex situations that are still unresolved by researchers worldwide. When suitable technology matures, it could be integrated into the UGV to enhance its autonomy.

Although autonomous navigation was achieved in this research, the current state of technology would face limitation in a more complex but genuine operational environment with the existence of dust, rain, muddy terrain, traversable vegetation, small static obstacles, dynamic obstacles and in the dark.

We shall be committing efforts and resources in future research on high fidelity perception technologies and navigation algorithm to address the identified technical challenges so as to develop an autonomous ground vehicle that could navigate robustly without being constrained by environmental and weather circumstances.

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